UAV Design-Part II
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Lecture-21
Power Plan Selection with Example

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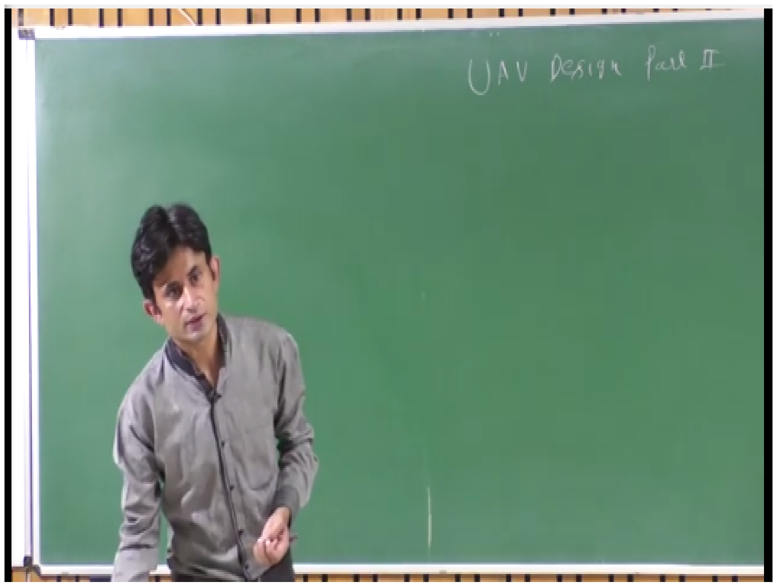

Welcome back, in last class we have seen the weight estimation process, also we have estimated the required weight in order to lift that weight how much wing area is required that also we have figured out. With this also we have found out the how much span is in order to distribute that area? How much wing aerodynamic chord is required in order to maintain the aspect ratio 10 which we have assumed selected?

We miss that what is the empty weight I have did not give the definition of the empty weight. So, in this class in a very; 5 second I will cover the definition of the empty weight. So, empty weight of the aircraft is nothing but if you have the complete aircraft weight, if you removed the crew weight, payload weight and fuel weight, what are the things you have that is called the empty weight.

In a weight the structures weight and power plant weight will come, ok. So, in this class we will see the engine selection. So, in last class you have estimated the weight for that weight to lift that weight how much area is required? That also we have found out. But you can observe that, you can notice that when your craft is flying in a steady state level flight or taking off or climbing?

In order to generate the aerodynamic lift your aircraft movement is required, so how will you move the aircraft? When you have the engine then only you can move the aircraft against the gravity like taking off climbing, ok. So, in this class we will do the engine selection, how we will select our aircraft engine? So, let us see. So, our first phase of aircraft is takeoff phase like, so we will stick to that phase later we will move on the cruise phase. So, based on takeoff phase how will you select their aircraft engine?

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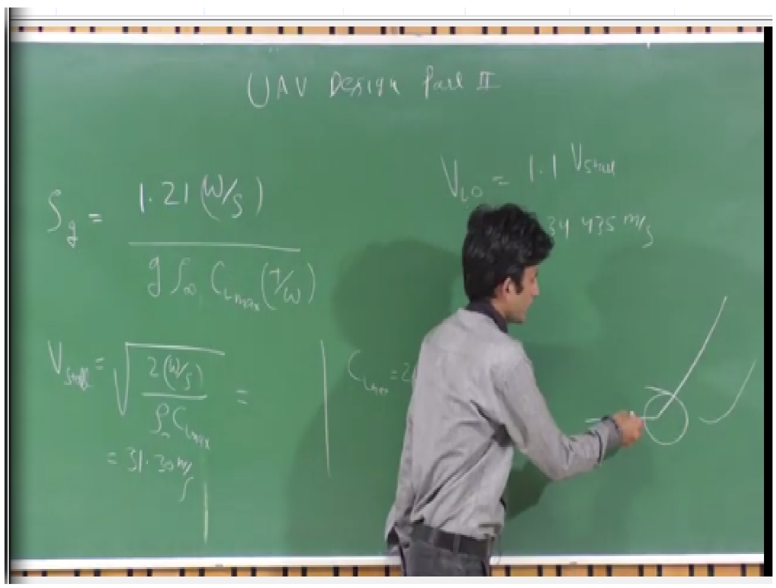

So, let us say your aircraft roll distance is defined by S g, this whole distance means your wheel is at the ground only, ok. This is nothing but 1.2 W by S g rho infinity C L max T by W thrust to weight ratio and this is W by S is a swing loading, ok. So, W by S we have already found out C L max with slight deflection we know ok. And we have to put the value of S g and we have to find out the value of T by W.

So, W we know, so we can find out the required thrust. So, before going to this we will find out the minimum velocity at takeoff. From that stall velocity we will find out the lift of velocity because there is a relation between the stall velocity, lift off velocity, stall velocity to cruise velocity there is a some percentage you can imagine like cruise velocity is 1.3 times on stall velocity takeoff velocity is 1.1 times of stall velocity.

So, first we will find out the stall velocity. So, as we know stall velocity of aircraft during takeoff phase is 2 W by S divided by rho C L maximum, ok. So, if you put all this value for time being consider C L max deflection is 2, ok. So, you just find out the stall velocity it will come 31.30 meter per second, you just the wing loading we have calculated at the stall approach and design cruise speed approach.

I am taking as a design crew's approach, so put W by S as that value, put C L maximum, put sea level density, you will get a start velocity. So, the rule says that your lift of velocity will be 1.1 times of the stall velocity for the present aircraft like for the new aircraft belongs to the general aviation category of, ok. So, that will comes turn out to be 34.435 meter per second that is your liftoff velocity.

See when you are taking off, you are not taking off directly from this directly to this. In this phase you required some kind of pull up manual, if you do like this your elevator will hit the ground. So, you have to pull up your aircraft with the (()) (05:46) 5 radius with a given velocity.

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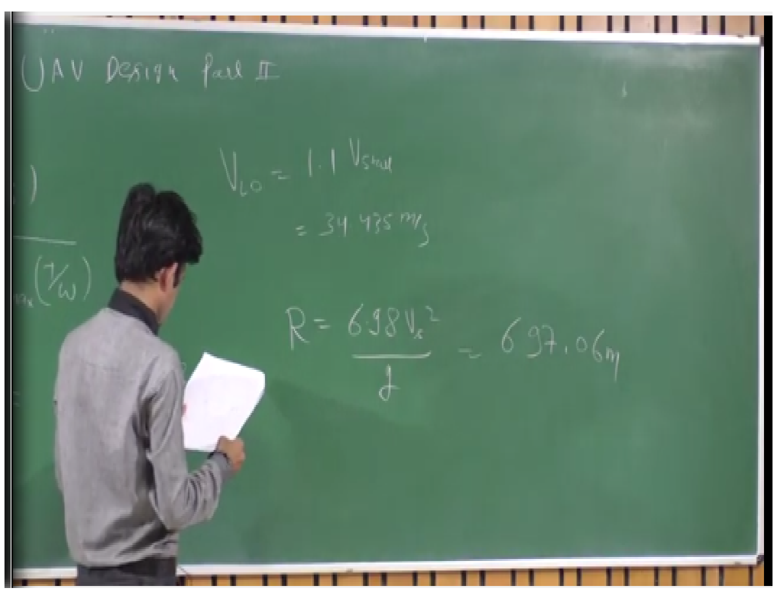

So, in order to pull up your aircraft in takeoff phase, your turn radius will be 6.98 V stall square by g, you just put the stall velocity you will get 697.06 meters pull up radius ok.

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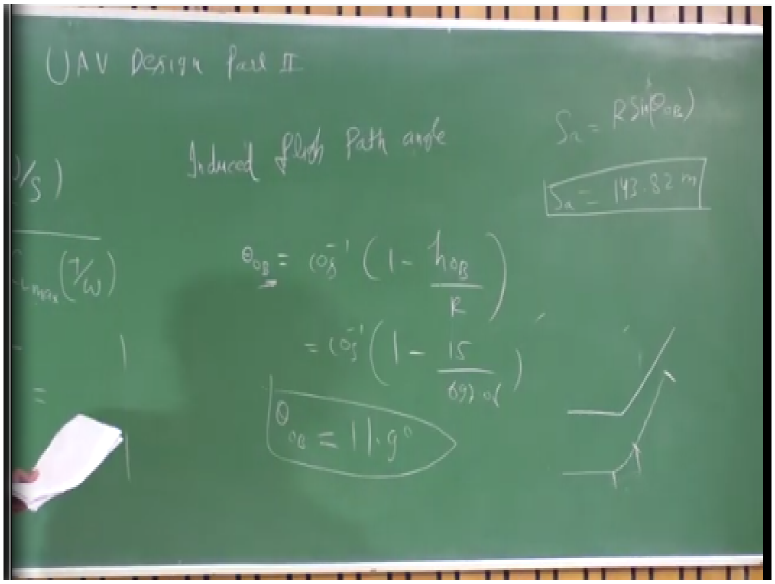

Now we will calculate the induced flight path angle, what should be our flight path during that takeoff? Very important. So, from geometry you will get theta tail theta cos inverse 1 – h OB Justin Pierce notation by R. So, basic a simple geometry, see when you are taking off first thing you have to consider that is screening height in a for certification of any aircraft there is a rule like DCCA or like aircraft rule there is a lot of aircraft rule is there, if you design an aircraft.

That tool you have to follow like minimum screening height like when you are taking off from runway you have to at least clear some obstacle distance, why? Because you are in beside the runway or after some distance from runway, there is a pole, there is a tree, so the length of the tree you have to clear that distance. So, one minimum distance is 5 that is nothing but the screening height which is nothing but h, ok, which is approximately 15 meter.

So, generally our trees and poles are less than 15 meters, right, 15 meters is required, ok. So, if you put h 15 an R which we have calculated, you will find, to clear this distance you need some angle, right, you need some angle, that angle is I am finding, ok. So, we need 11.9 degree angle, ok, that angle. And you can notice that as we already know your aircraft will not take off like this, your aircraft will be like this.

So, to this distance there is a airborne distance, your aircraft is above the ground but not climbing, climbing will start from here to here, this is the rolling part. So, this distance is nothing but called the airborne distance. So, that can be written as S = R sine theta OB and this is sine, ok, R sine theta OB. If you put you will get 143.82 meter, this is airborne distance, ok, 153 meter. So, in the last lecture I have given you the takeoff distance as specified, the takeoff distance is specified was 550 to 650 meter, for time being let us consider our we want takeoff distances 600 meter.

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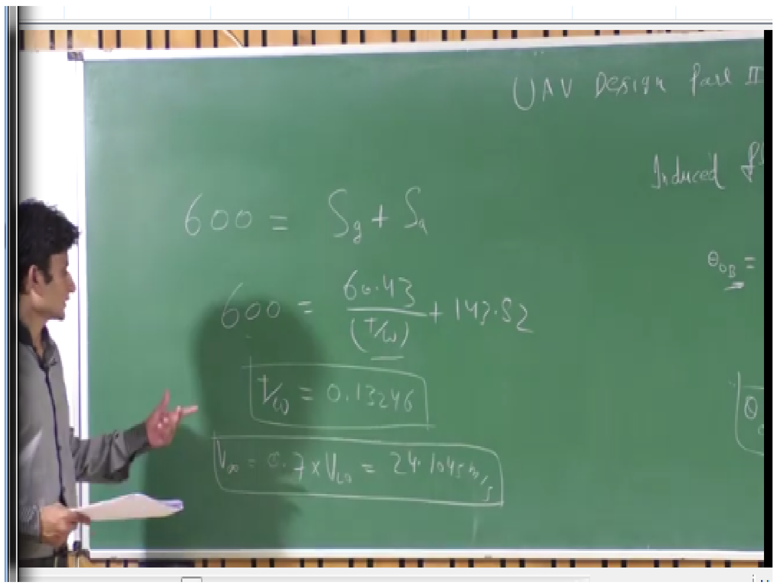

So, total takeoff distance is 600 meters, right, and what is takeoff distance? Is nothing but the ground roll + airborne distance, ok. So, I have given one formula to you S g = 1.21 W by S 0 infinity C L max T by W, if you put W S g which is nothing but 9.81, rho is 1.225, C L max is 2, you will get the relation between S g and T by W which is turned out to be 60.43 divided by T by W + 143.82 and this is 600.

Now only one parameter is there T by W rest here are the numerical values, you can bring T by W here, do the mathematical calculation, you will get T by W 0.13246, ok, this is T by W, ok. How will you find the liftoff velocity? The question is, see T by W you know but at this tells that what is the thrust loading is in required in order to takeoff but at what velocity? So, that velocity you can find out, liftoff velocity we have found out, right, 1.1 into stall, yeah yes already we have found out.

But what is your at this like based on this data how will you select the engine? Based on liftoff velocity you are not selecting engine based on stall velocity you are not. Like what is a free steam velocity whose speed based on that you will select the engine, right. So, generally V infinity taken as a 0.7 into V liftoff for the present case, ok, so you will get 24.1045 meter per second. Why we are finding this velocity? Because we need power, based on the power we will select the engine.

So, for power we want we required thrust as well as velocity, if your power required is nothing but thrust into velocity. So, thrust we have, velocity we do not know, we have found out, so based on that thrust we know, velocity we know. So, if you multiply both of them, then we will get the power and based on that power we will select the engine. But you can notice that we are taking free steam velocity 0.7, we are multiplying 0.7.

So, this is nothing but the cruise speed, this is not liftoff velocity, this is not stall velocity. And this is not also the final criteria for selecting the engine, we will go for climb also, we will go for cruise also. In cruise we will fly the maximum velocity but because sometimes suppose that you have selected the engine based on the design speed which is nothing but 70 meter per second, will these meet the requirement? Certainly no.

Because you sometimes you need maximum velocity, you want to cover the distance as soon as possible. So, you have to required more velocity maximum velocity, you want to demand maximum power from the engine sometimes. So, in that condition we should select the engine based upon the maximum velocity because when a speed increases at a maximum speed if you select the engine your power requirement is more.

So, if power requirement is more and sometimes if you demand the less power then automatically the requirement will be meet but if suppose that you have selected the engine based on the lower speed and sometimes your demand is more then you cannot meet the requirement. So, it is better to select for the maximum velocity instead of selecting your power plant based on the design speed.

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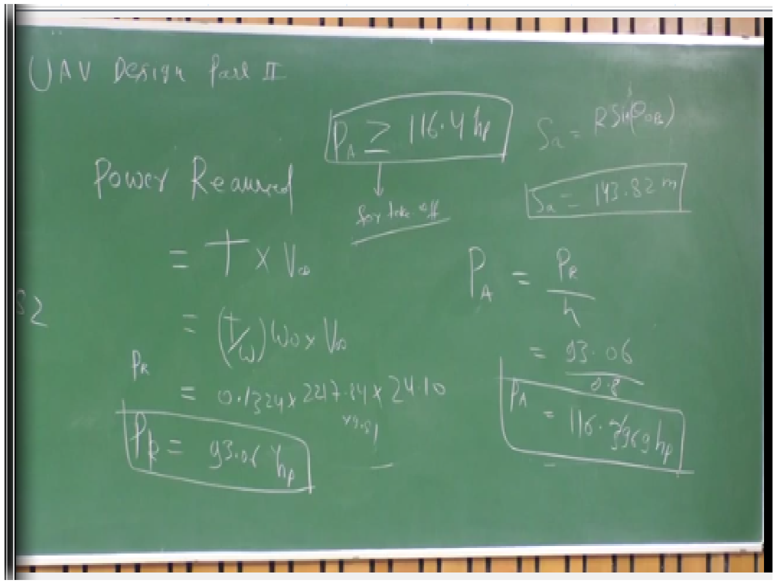

So, now what is our power required? So, simply power required thrust generated into velocity, you can modify it this is T by W into W0 into V infinity, T by W you know, 0.1324, takeoff weight you have estimated 2217.84 kg into speed you have find out, 1.12 24.10. So, this will come into what divided by 746, you will get in hp to power required will be 93.06 hp but remember this is not the final one, ok.

So, this will be the 93.06 hp but these are the power required, but what the power is coming that is coming from engine transferring to the shaft, propeller is rotating then there will be some amount of loss will be there, right. Like what the power it develop our engine cannot directly 100% cannot be transferred into the shaft, there will be the loss. So, you have to take the efficiency of the propeller, propulsion efficiency.

Then power available is to you will be this, this is power required, ok. So, actual power available will be power required is 93.06 divided by 0.8 this will be nothing but 116.3969 hp, this will be. Notice that power required this is in kg, right, so you have to multiplied by 9.81 hours in order to (()) (17:36) ok. So, your power available is 116.39 hp, ok. So, conclusion can be draw from here, like for taking off at least your power should be 116.

So, as a designer you will write power available should be greater than or equal to 116.4 hp for takeoff, remember this value, we will surprise when you will calculate the power at climb and cruise condition. So, our second phases obviously climb, ok, now we will move to the climb. See I feel that there is some expression like take off distance and you might not have aware, so that is why I have given you two references please go through that. If you do not understand anything please directly post on the forum I am promising that I will give the answer, ok.

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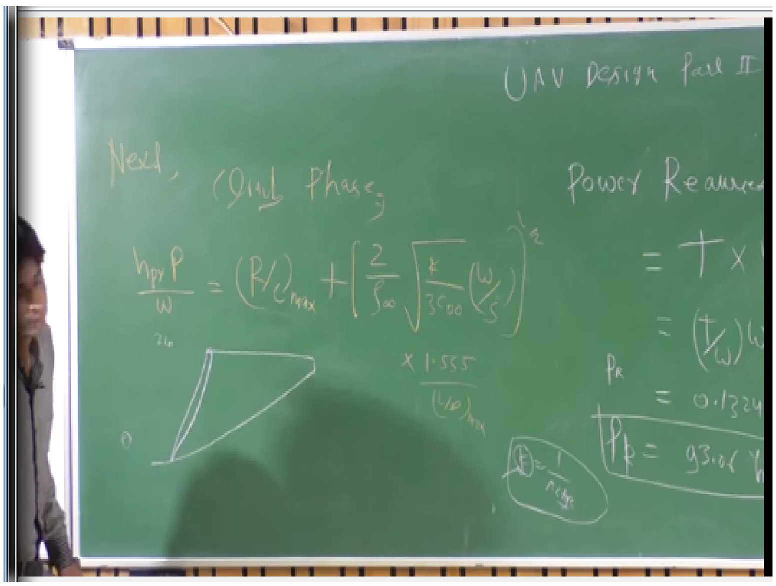

So, now next is we will go in a climb phase, so in climb phase you will use this. See derivation I am not explaining you because we do not have the purpose of this lecture is to give the idea of how to design the aircraft not for the derivation, for derivation you just follow the book, ok, that is why I am writing only expression if you by your demand if you want I can give you the derivation also, we just post on the forum.

R by C max + 2 divided by rho infinity under root k 3 C D 0 W by S, this is whole power 1 by 2 into 1.555 L by D max, ok. So, now I think you are aware of propeller efficiency power W, sea level densities, C D 0 is nothing but the parasite drag coefficient, you write drag polar = C D = C D 0 + k C L square, that C D 0 is here, k is induced drag factor if your wing is so large this value will be very less.

If your wing is very short this value will be more because k is nothing but k is 1 upon pi into E as per ratio, if your as per ratio is more your induced drag factor will be very less, if your as per ratio is less this value will be more. So, fighter aircraft this value will be very more and for glider this very low, ok. So, you just notice that, I also given the maximum rate of climb I think it is 5 to 6 meter per second yes rate of climb, it is also the requirement.

Because why it is a requirement? You can understand from this graph like. Suppose that you are taking from this point, ok, you want to climb let us say 0 to 2 kilometer, ok, if you are taking very small flight path angle you will cover this much distance, if your flight path increases this will take less time to reach this point. More if you increase the flight path angle, it will take very quick to attend this 2 kilometer to is depending upon, at what rate of claim you are flying, ok.

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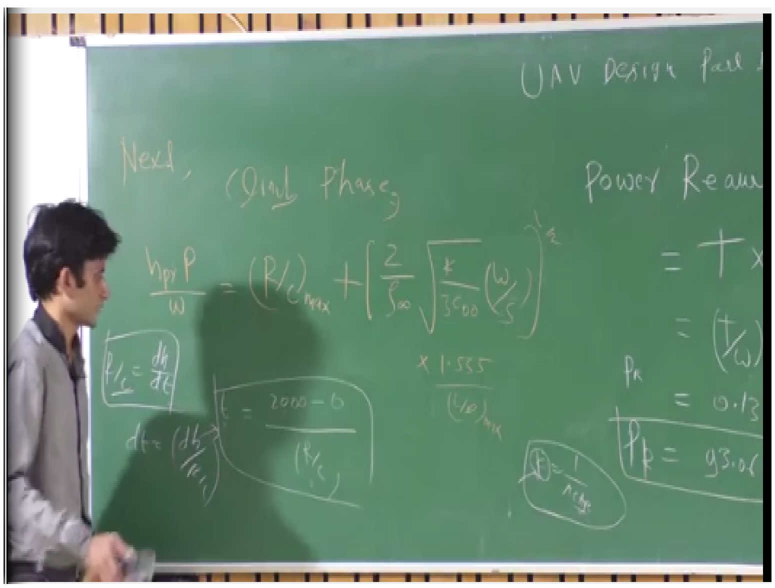

So, that is also the requirement, simply the rate of climb is nothing but R by C = dh by dt, if R by C is dt you can write dh upon R by c, ok. Further suppose that your initial altitude is final altitude is 2 kilometer like, 200 initial altitude is 0, your R by C is some value and your time will be directly I am writing this to this, ok. So, as R by C increases, you will require less time to reach the 2000 meter, so that is the importance of rate of climb. So, that is why I have given the rate of climb requirement also, ok. So, now if you put all this value I am putting R by C max 5, 4 with the present case.

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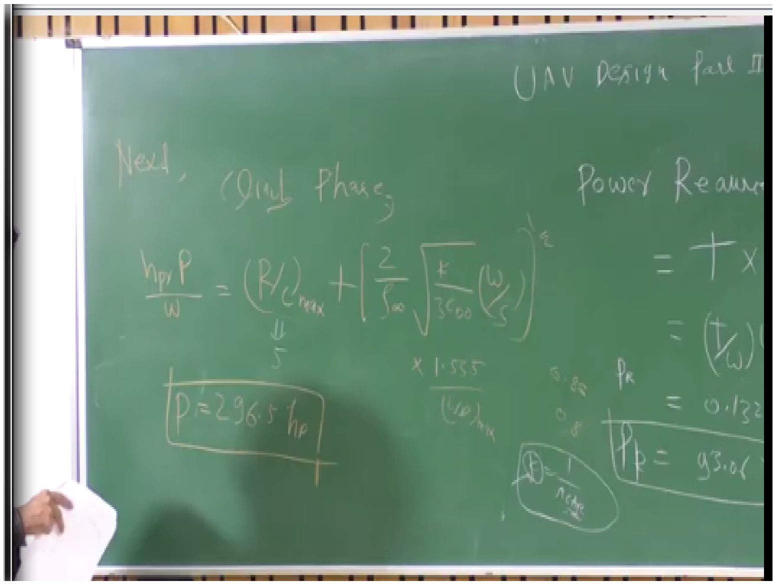

This value is I am putting 5 this value was know is 13, k C D 0 you can calculate ok, C D 0 for the present case you just assume 0.035. Remember that the C D 0 value is will change in the flight also, C D 0 value is a parasite drag coefficient. Sometimes during the landing you will deploy the landing gear, the C D 0 value increase. If during the takeoff, during the landing, you will deflect the flap, deflecting the flap will change the C D 0 value.

Deflecting the control surface if you want to execute the maneuvers like rolling yawing, pitching you will deflect the elevator. So, sorry you will deflect the control surface, for pitching you will deflect the elevator, for rolling you will deflect the aileron primary, ok and for yawing you will deflect the radar. So, control surface deflection will change the C D 0 value.

So, this value will change in flight but for the present case we are estimating the constant because max to max the change will be the 3%, 4%, ok. So, that is why we are assuming constant. So, you just take C D 0 = 0.035, take R by C max 5, put the propose efficiency already we have told you how much value you have to take, ok, k value you can find out 1 upon 0.2 into as per ratio, as per ratio you know, e you just take 0.8 0.825 depending upon the your shape of the wing.

If it is elliptic your e will be 1 but generally elliptic confrontation does not exist. So, you just take it 0.85 for 8 you will get k C D 0 already I have told you. Then loading, we have already estimated, you will find out the power required during the climb will be 296.5 hp power is required, ok. So, you can see that this much power is required in order to climb.

So, as a designers what you will conclude? You will conclude our power requirement for to perform the climb should be greater than 296.5 hp. You can notice this two number 296.5 hp and at the takeoff 116.4 hp, this is more, why more? Because during the climb you have to climb as well as with the thrust you have to lift the weight also. Like when you in the climb if you resolve the forces let us say you are climbing like this.

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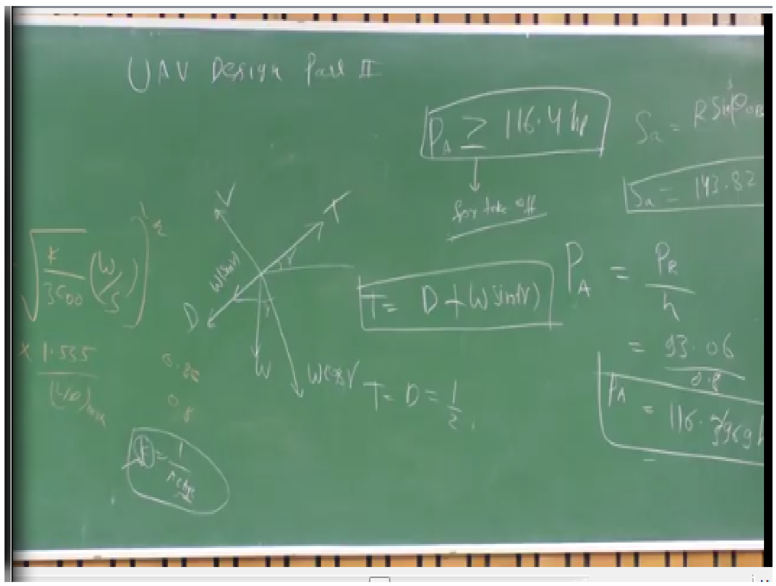

So, your thrust direction will be this and your drive direction will be opposite and your lift will be perpendicular to the free steam velocity, ok. And your weight will act at the downward direction and this angle is nothing but this from this flight path angle you are flying, ok, so this also become the gamma, ok. So, this component will be W cos gamma, right, and sine component will come here, W sine gamma, ok.

So, what is your thrust at a steady state claim? Net force will be balance, right. So, T will be nothing but the D, D is aerodynamic drag plus one weight component also is coming, so W sine gamma, ok. So, at cruise condition gamma is 0, you are maintaining the height ok, so thrust will be the drag but here thrust is the D + W sine gamma. So, apart from drag you are lifting the weight also and see this weight D + W, right.

So, your thrust requirement will be more of your thrust requirement will be more power is what? Thrust into velocity, your power will also be more. So, that is why our power in climb is coming more than of than takeoff, so I hope you got this. So, next we will go for the, as exercise I am giving you third phase is cruise, so you just take thrust equal to drag which is nothing but half rho V square, ok, first we will erase this thing then we will explain.

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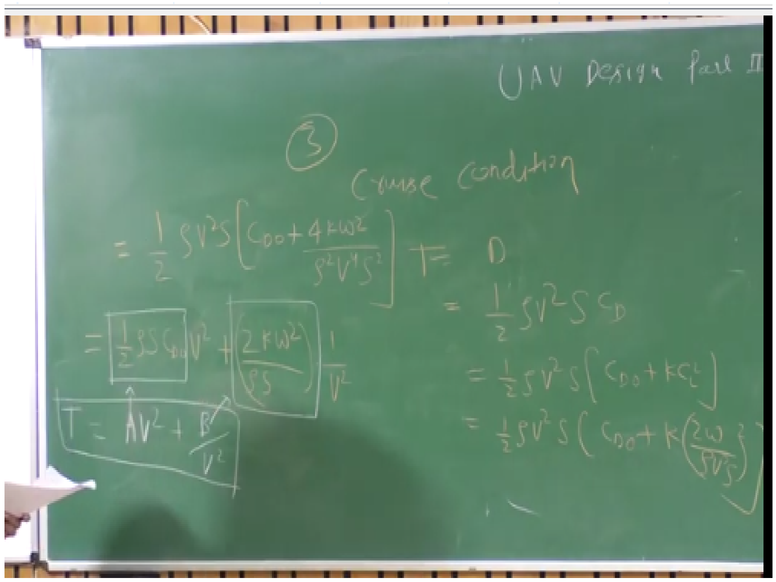

So our third phase is cruise condition, this type of cruise a steady state on level flight, ok, thrust is nothing but drag, drag you can write half rho V square S into C D, half rho V square S C D further you can write C D 0 + k C L square, right, ok. C L what you can write? 2W divided by rho V square S from left you are going to write right. You just put C L value here, what you will get? Half rho V square S C D 0 + k 2W rho V square S whole square, ok, this thing you will get now.

In one more what you will get? half rho V square S C D 0 + 4 k W square, rho square V power 4 S square, right. In one more step you will get 1 by 2 rho S C D 0 V square, ok, and 2, this 2 will cut from 4, 2 kW square rho and one rho will get cancel, one rho will be remaining and S and S square S will be there and 1 by V square. Let me check half rho by C D 0 V square 2kW square rho S by V square, ok.

Just notice here, this value is constant for a given flight condition whereas this value is also constant, ok. So, this thing you can write AV square + B by V square this is thrust, ok, A is nothing but this and B is nothing but this, ok.

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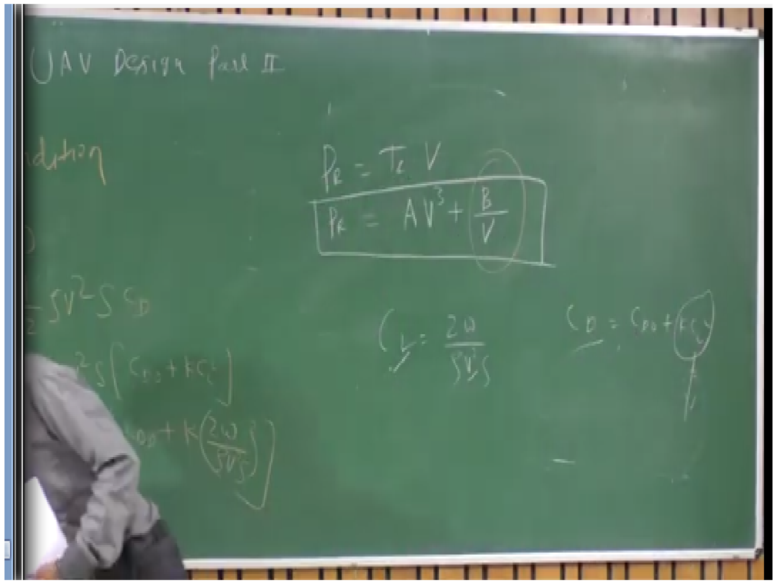

So, now power will be thrust required into velocity this T is nothing but the thrust required. So, if you multiply by V you will get AV cube + B by V this is your power requirement, ok. So, the observation can be made here, as soon as you increase your flight velocity, your this part will go down and this part will rise up. So, this is nothing but the induced drag, this part is induced drag, this is profile drag.

So, the thrust requirement is coming from here it is profile and from here it is induced, ok. And this is nothing but called this if you increase the velocity your induced power this term is nothing but the call the induced power, ok. So, induce power will decrease as soon as you increase the velocity but your profile power will increase, why it is happening like when you increase the velocity you are in induced drag is going down?

So, you can observe that as soon as your increase your velocity, suppose that your aircraft is angle of attack a degree. If you increase if you want to maintain the same altitude and you are decreasing the angle of attack. So, decreasing the angle of attack by this equation C L = 2W by rho V square S, decreasing the angle of attack means you are decreasing the C L to balance the lift = weight, V automatically will increase.

So, C L value you are decreasing, so if C L value decreasing from C D = CD 0 + k C L square, drag will also increase this part will decrease, right. So, this is nothing but the induced drag part. So, if this decrease the thrust will also decrease and power will also increase but it will not increase in the same manner, this is V square and this is V, ok.

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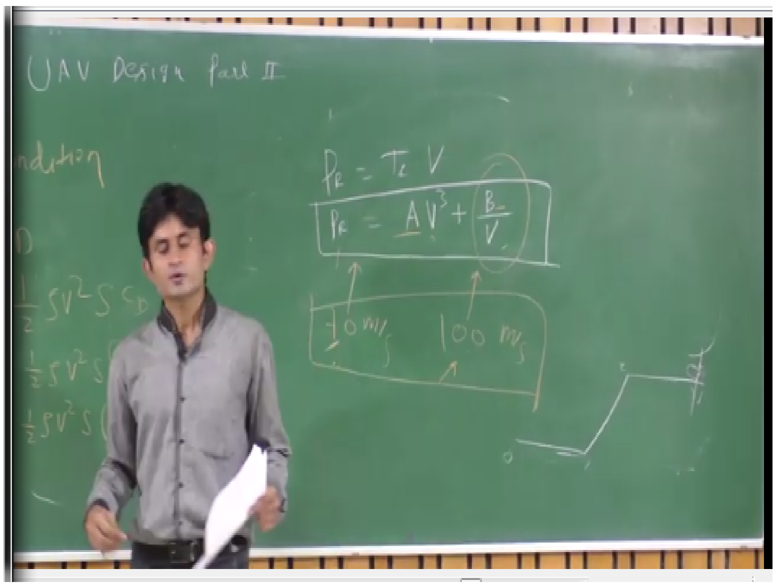

So, now, you can notice that, in flight if C D 0 is constant this A and B value will be constant. So, if we put the maximum velocity you will get the maximum power. So, already I have given you the design cruise speed 70 meter per second to 100 meter per second, right. This is designed if you calculate based on this speed your power required minimum will be obviously minimum, right, will not be more compared to the 100, ok.

So, suppose that you have selected the engine based on 70 meter per second, ok. But sometimes you need to fly at the 100 meter per second also. So, the requirement will not meet and if you select the 100 meter you can fly it and 90, you can fly as the 80 also, you can fly as the 70 also. So, you have to select based on the maximum velocity, you just put the maximum velocity you will get the power required in order to perform the cruise at a maximum velocity.

So, this is all about the power requirement, that means engine selection also you can notice that we have written C D = C D 0 + k C L square C L = 2W divided by rho V square S. And we are cruising profile this you know takeoff, climb, cruise this is 2 to 3, right, if it is 1 and if it is 0, ok, your fuel is continuously consuming. So, there is a method like mid course weight like we have to take the average weight not S W 0.

Because if it is let us see C D 0 k C L square W you are putting at a takeoff weight but in reality this is not the takeoff weight which we have estimated it will be less than. So, there is a concept like mute cruise weight. So, I am giving as exercise, please go through that what is this mid cruise weight estimation? So, we will find out the average value of W 0, then you put this value you will get the power, ok, so this is all about the engine selection.

So, let us summarize our last lecture and this lecture what we have done? ok. So, again I am requesting you if you did not get anything you just post on the forum, I will give the answer. So, let us one by one we will summarize.

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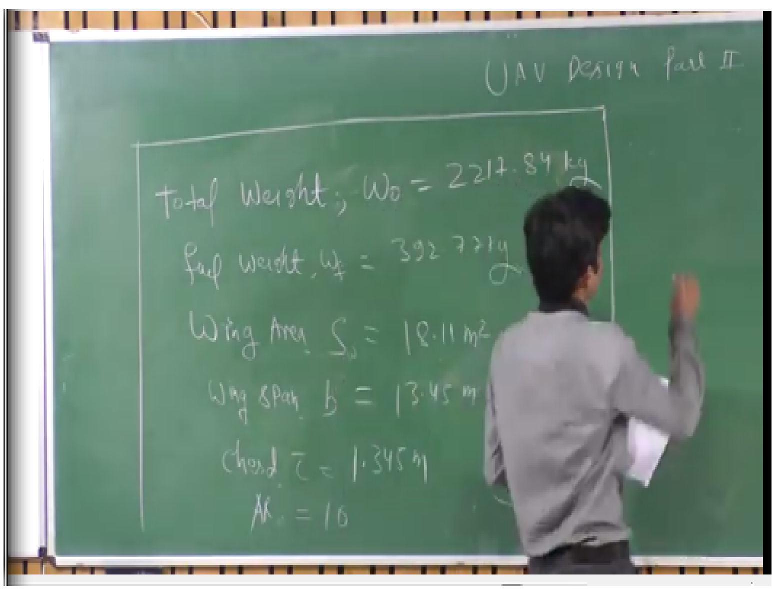

First we have estimated the total weight, total weight is estimated W 0 is 2217.84 kg, ok. Fuel weight in order to cover the 1000 kilometer range 392.77 kg is required, which is approximately 17%, in order to lift the total weight of the aircraft the wing area S W you can say or S we have calculated 18.11 meter square. To distribute this area we have calculated the wingspan which b in symbolic nothing but 13.45 meter.

By fixing the aspect ratio we got the chord nothing but c bar or mean aerodynamic chord is 1.345 meter, ok. Aspect ratio obviously we have fixed as a 10, ok if something you are fixing and finally you are you are getting what you required? That mean what we are fixing it is a correct value, ok.

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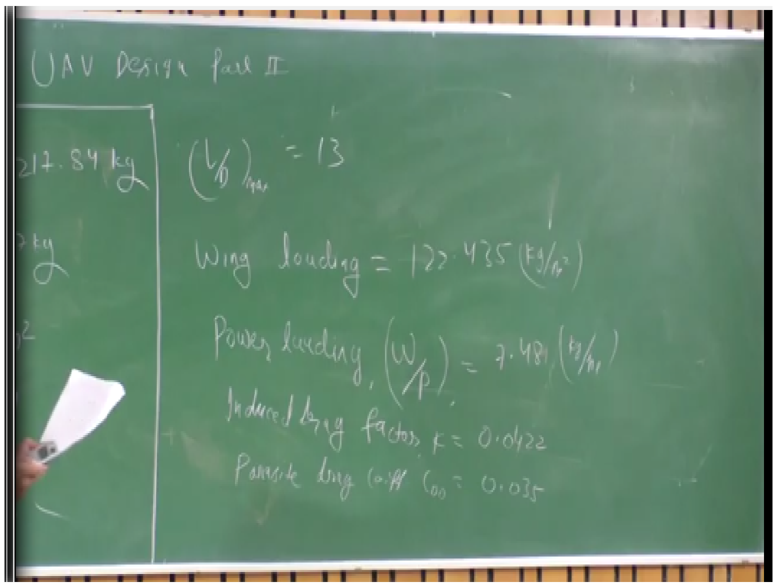

L by D max will effects as a say 13, ok, wing loading we have calculated, wing loading we have found out, I am writing only based on design a speed approach. However we have calculated based on the stall approach also. Power loading it is not as a same as wing loading, power loading will be nothing but the W by P is 7.48 kg by hp. This power loading is depend upon it which condition you are taking at a cruise or climb, so these are will be different, ok.

K value induced drag factor we have calculated 0.04 based on the configuration we assume that C D 0 which is parasite drag coefficient 0.035, ok. So, this power loading is nothing but is based on the let me check if power loading is based on what? Based on climb or based on takeoff, so, this power loading is nothing but the based on the climb. So, these all about the summary of the last lecture and present lecture if you have any doubt then please post on the forum. Again I am saying you I am promising that I will give the answer, thank you so much for attending this lecture.